# (12) UK Patent Application (19) GB (11) 2 061 138 A

(21) Application No 7936892
(22) Date of filing 24 Oct 1979
(43) Application published
13 May 1981
(51) INT CL$^3$
B21D 53/88
(52) Domestic classification
B3A 73
B3H 2U
(56) Documents cited
None
(58) Field of search
B3A
B3H
(71) Applicants
Cam Gears Limited, 45
Wilbury Way, Hitchin,
Hertfordshire
(72) Inventor
David James Hoare
(74) Agents
Urquhart-Dykes & Lord,
11th Floor,
St. Martin's House,
140 Tottenham Court
Road,
London, W1P 0JN

(54) **Manufacture of rack member for rack and pinion assembly**

(57) A longitudinally extending rack member for a rack and pinion assembly is formed from a tubular metal bar 1 having longitudinally extending grain 9 over the length of the bar within which the rack teeth 4a are to be formed. The rack teeth 4a are formed by collapsing the wall of the bar 1 to close its bore 2 and by coin pressing the collapsed wall between opposed dies so that the metal grain 9a follows the form of each tooth and each tooth 4a is devoid of end grain. For a thin walled tubular bar, a tubular plug can be located in the bore of the tubular bar and the walls of the bar and plug are subsequently collapsed to close the bore of the plug. The walls are coin pressed to form the rack teeth.

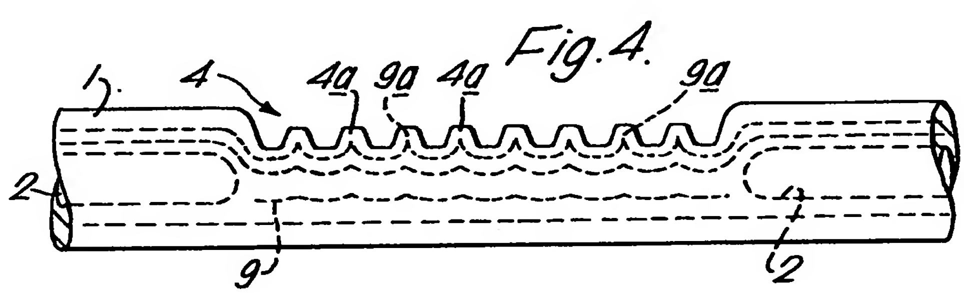


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Fig. 1.

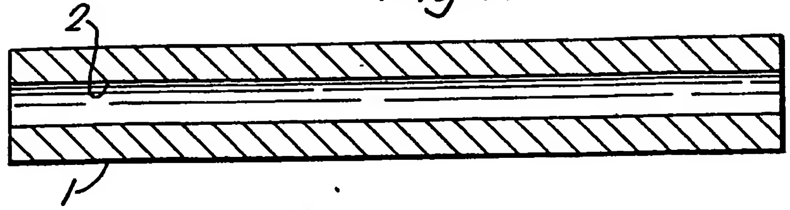



Fig. 2.

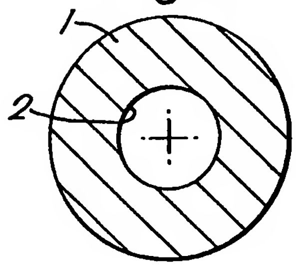



Fig. 5.

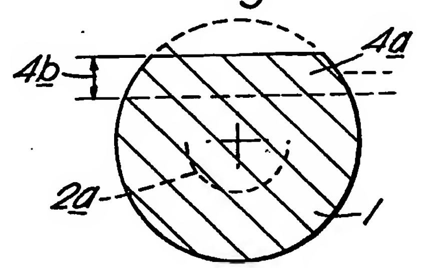



Fig. 6.

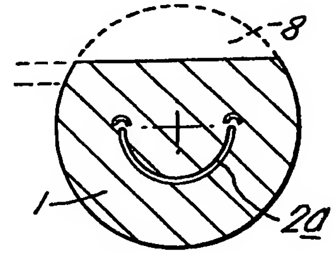



Fig. 3.

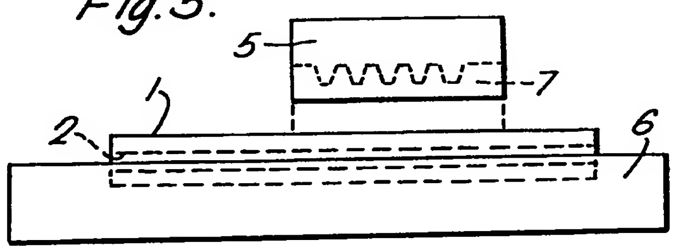



Fig. 4.

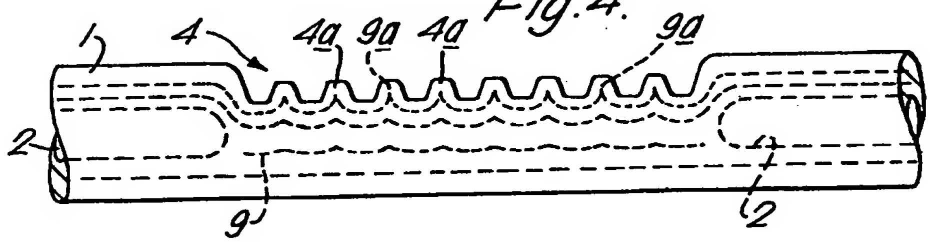
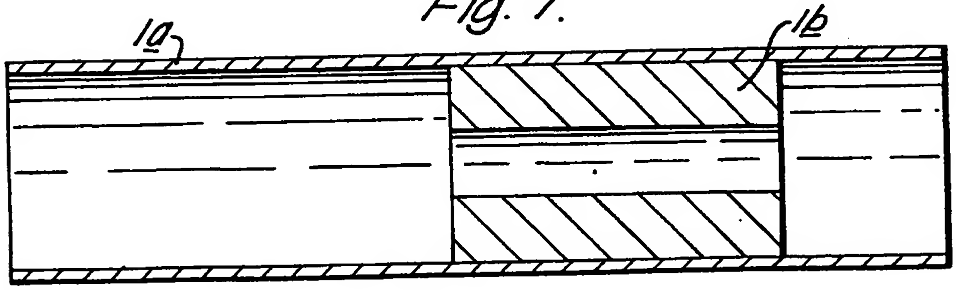



Fig. 7.



SPECIFICATION

**A method of manufacturing a longitudinally extending rack member for a rack and pinion assembly**

This invention relates to a method of manufacturing a longitudinally extending rack member for a rack and pinion assembly.

Rack and pinion assemblies are well known, particularly in the art of steering gears, whereby the rack member has a longitudinally extending array of rack teeth each of which extends laterally of that member. When incorporated in a rack and pinion assembly, the rack member is longitudinally displaceable in a housing while the rack teeth engage with the teeth of a rotatably mounted pinion, so that upon rotation of the pinion the rack is displaced longitudinally. The teeth of the rack member can take many different profiles to provide the desired engagement with the pinion and a required ratio of drive which is transmitted through the assembly usually from the pinion to the rack bar. In use the rack teeth can be subjected to considerable shear forces, especially in a steering gear installation and consequently the material and profile of the teeth must be of a form and design which is sufficient to withstand such forces and thereby alleviate fracture of the teeth.

It has previously been proposed to manufacture a rack member as described above from a tubular workpiece to provide a relatively lightweight structure. In such a technique, an example of which is disclosed in U.S. Patent No. 4,133,221, a collapsible mandrel is inserted into the tube, the wall of the workpiece is displaced radially inwardly over the mandrel to form the rack teeth and the mandrel is then collapsed and withdrawn from the workpiece. The radial displacement of the workpiece wall is effected by a die part which is generally complementary to the opposing die part formed by the collapsible mandrel so that the wall of workpiece adopts a corrugated profile corresponding to the desired tooth formation when the wall is pressed between the opposed die parts. It is necessary for the mandrel to collapse to ensure that it is sufficiently clear of the internal profile of the formed teeth to permit its withdrawal from the rack member; such a collapsible mandrel is relatively expensive to produce and is expensive to use in that it is time consuming to collapse and withdraw following a tooth forming operation and also to assemble and locate in preparation for a tooth forming operation.

It is an object of the present invention to provide a method of manufacturing a rack member which may be relatively lightweight and which method is relatively inexpensive, is applicable to a wide variation of tooth structure – this variation may be as between one type of rack and another or as between individual teeth on the same rack where variable ratio steering is involved and it facilitates the manufacture of robust teeth.

According to the present invention there is provided a method of manufacturing a longitudinally extending rack member for a rack and pinion assembly, said member having a longitudinally extending array of rack teeth each tooth of which extends laterally of the member and which method comprises providing a metal bar which is tubular at least over its longitudinal extent where the rack teeth are to be formed, collapsing the wall of the bar substantially to close the bore and displacing the material of the bar to form therein the array of rack teeth on the collapsed wall of the bar.

Further according to the present invention there is provided a longitudinally extending rack member when manufactured by the method as specified in the immediately preceding paragraph.

By the method of the present invention the wall of the tubular bar can be collapsed to substantially close the bore over the length (or appropriate part length) of the bar and the material of the collapsed wall subsequently displaced to form the rack teeth. Preferably however the collapsing of the tubular bar (or the required longitudinal extent thereof) is effected simultaneously with the displacement of the bar material to form the rack teeth.

The displacement of the bar material to form the rack teeth can be achieved by a forging technique but it is preferred that a press technique is utilised, particularly coin pressing. Coin pressing is well known for metal shaping whereby the shape of a metal blank is changed without a change in volume by subjecting the blank to pressure between opposed dies so that the metal is displaced into a form determined by the die cavity. This coin pressing technique can be applied to the manufacture of a rack member in accordance with the present invention whereby the tubular metal bar workpiece is subjected to pressure between dies causing the wall of the tube to collapse (if not already collapsed) simultaneously with the formation of the rack teeth. Furthermore, by arranging for the grain of the tubular metal bar to extend longitudinally of the bar, an advantage can be provided whereby the grain will substantially follow the form of each tooth in the array of coin pressed teeth to be continuous over such array and each tooth is devoid of end grain (which alleviates fracture of the teeth). In conventional manufacture of rack members where the teeth are subjected to a machining operation, the cutting of the metal workpiece causes end grain to be exposed in the flanks of the teeth with the result that when the teeth are subjected to shear forces during use of the rack member the discontinuous grain can provide lines of weakness along which the teeth can fracture. Coin pressing permits an accurately shaped rack to be formed solely as a result of the pressing operation which avoids the requirement for subsequent machining and by arranging for the grain of the rack member to follow the form of each tooth and to be continuous longitudinally over the array of rack teeth so that each tooth is devoid of end grain as aforementioned, the grain provides continuous longitudinal support throughout the teeth to withstand

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

the aforementioned shear forces. Furthermore, by appropriate selection of the opposed dies between which the metal bar is coin pressed the array of rack teeth can be shaped with widely different profiles, both one rack as compared with another or between different teeth on a common rack as would be the case with a variable ratio rack member.

The metal bar will usually, but not essentially, be tubular over the whole of its length and the wall of such bar may be collapsed to substantially close the bore over part length only of the bar (which part length is appropriate for the length of the rack teeth) while at least one end part length of the bar is retained in tubular form. This facilitates the manufacture of a relatively light weight rack member with reduced material costs and also the tubular part length or lengths which are retained on the rack member can provide convenient coupling points or housings, for example, to mate with or receive ball joints by which the rack member can be connected to control links in a steering gear.

If required the bar can be heated, say at least over the part length of the bar within which the rack teeth are to be formed, to facilitate flow of the metal during coin pressing. Conventional rack members are usually machined from high carbon steel which is then hardened whereby the surface of the member is heated and is then cooled rapidly by quenching. High carbon steel is expensive in comparison with low carbon steel and the possibility is envisaged that the tubular metal bar from which the rack member of the present invention is to be formed may be of a low carbon steel which, by subjection to the coin pressing operation becomes work hardened. By arranging for the grain of the rack member to extend continuously through the rack teeth and by having each tooth devoid of end grain it is possible that the strength which this affords to the rack teeth will alleviate the requirement for a hard surface to be provided on the teeth by use of expensive high carbon steel and that the less expensive lower carbon steel may be suitable as aforementioned.

The internal profile of the opposed dies, particularly the part of the profile which is complementary to the rack teeth, can be formed under computer control. This is particularly advantageous where the rack teeth are, for example, to be non-uniform as in the case of a variable ratio rack and pinion gear which incorporates a standard uniformly toothed pinion. With this in mind the form of the proposed rack teeth may be determined mathematically and a computer programme may be produced in accordance with such theoretical calculation; this programme may then be utilised to computer control an appropriate tool for machining the desired profile on the die with which die the rack teeth are to be coin pressed.

One embodiment of a method of manufacturing a rack member for a rack and pinion assembly and in accordance with the present invention will now be described, by way of example only, with reference to the accompanying illustrative drawings, in which:–

Figure 1 is a side elevation of a longitudinally extending tubular metal bar from which the rack member is to be formed;

Figure 2 is a radial section of the bar in Figure 1;

Figure 3 is a side elevation of the opposed dies of a coining press and diagrammatically illustrates the manner in which the bar of Figure 1 is subjected to deformation by coin pressing;

Figure 4 is a side elevation of part of the rack member formed by a coin pressing technique and from a bar shown in Figure 1 and diagrammatically illustrates the grain in the rack member;

Figures 5 and 6 are radial sections of the metal bar during and following the deformation thereof and are used to diagrammatically illustrate a preferred volume relationship between the size of the bore of the tube in Figure 1 and the size of the formed rack teeth and

Figure 7 is a side elevation of a modified form of tubular metal bar from which the rack member can be formed.

The longitudinally extending tubular metal bar 1 shown in Figure 1 may be of low carbon steel, is generally cylindrical and is provided with a cylindrical bore 2. Male or female screw threads (not shown) can be provided at each end of the bar to provide a convenient means of coupling linkage members to the rack member which is to be formed from the bar and when incorporated in a rack and pinion assembly (as for example in a steering gear installation). The bar 1 is formed, for example by a rolling process, so that the grain thereof extends longitudinally and continuously throughout the length of the bar.

Part length of the bar 1 remote from its tubular end part lengths is subjected to a coin pressing operation as shown in Figure 3 whereby the wall of the bar over the desired longitudinal extent of the rack teeth which are to be formed is collapsed to close the bore 2 (Figure 6) and the metal of the bar in this region is displuced to provide a longitudinally extending array of rack teeth 4 (see Figure 4) each tooth *4a* of which extends laterally of the bar 1.

As shown in Figure 3 the bar 1 is located between the upper and lower dies 5 and 6 of a coin press of which the cavity 7 in the upper die 5 is of complementary shape to the array of rack teeth 34 which are to be formed on the bar 1. The dies 5 and 6 are closed under pressure to cause, substantially simultaneously, the wall of the bar 1 to collapse and the material of the bar to be displaced and flow into the toothed regions of the cavity 7 and thereby mould the teeth *4a* to such accuracy that subsequent machining of the rack is avoided. It is believed that the considerable pressure to which the material of the bar 1 is subjected during coin pressing will work harden the surface of the rack teeth *4a* sufficiently to withstand the wear to which they are likely to be subjected in use even though the bar metal is of low carbon steel. If required the bar 1 can be heated prior to the coin pressing operation to facilitate the metal displacement between the dies 5 and 6.

The cavity formed between the closed dies 5 and 6 is of course accurately shaped to correspond with the rack teeth *4a* irrespective of whether all of the teeth are of the same profile and dimensions for a standard rack or whether the teeth differ one from the other as in the case of a variable ratio rack. Furthermore, the dies 5 and 6 serve to change the

shape of the metal of the bar 1 over the part length of the bar where the rack 4 is to be formed without changing the volume of the metal in that region. For the purposes of calculation it may be assumed that when the wall of the bar 1 is collapsed to close the bore 2 (as shown at *2a* in Figure 6) a recess 8 is formed in the peripheral surface of what may be considered to be a solid bar over the length of the collapsed bore part *2a* and the volume of the recess 8 is equal to the volume of the bore part 2 prior to the closing of that bore part. From these considerations the dimensions of the bore 2 and the diameter of the bar 1 which are required to provide rack teeth *4a* with desired pitch, profile and depth characteristics (as indicated in Figure 5 where the depth of the teeth *4c* is shown at *4b*) can be calculated without difficulty.

During displacement of the metal in the coin pressing operation to form the teeth *4a* the grain of the bar which was continuous over the length of the bar maintains its continuity as indicated by the chain lines 9 in Figure 4 but is displaced as indicated at *9a* to substantially follow the form of each tooth. Since the teeth *4a* are formed with such accuracy that their subsequent machining is avoided, each tooth *4a* is devoid of end grain and the continuous grain throughout the array of rack teeth provides reinforcement which serves to alleviate fracture of the teeth, particularly over their crests.

In the event that the rack member is to be formed from a thin walled tubular bar (as for example may be required to reduce weight) such a bar shown at *1a* in Figure 7 may be provided with a tubular metal plug *1b* over the longitudinal extent where the rack teeth are to be formed. During the tooth forming operation the wall of the plug *1b* is collapsed to close the bore thereof while the metal of the plug together with the metal of the bar *1a* is displaced, preferably by the coin pressing technique above described, to form the array of rack teeth.

CLAIMS

1. A method of manufacturing a longitudinally extending rack member for a rack and pinion assembly, said member having a longitudinally extending array of rack teeth each tooth of which extends laterally of the member and which method comprises providing a metal bar which is tubular at least over its longitudinal extent where the rack teeth are to be formed, collapsing the wall of the bar substantially to close the bore and displacing the material of the bar to form therein the array of rack teeth on the collapsed wall of the bar.

2. A method as claimed in claim 1 which comprises collapsing the tubular bar or the required longitudinal extent thereof substantially simultaneously with the displacement of the bar material to form the rack teeth.

3. A method as claimed in either claim 1 or claim 2 in which the metal bar is tubular over its longitudinal extent and the method comprises collapsing the wall of said bar substantially to close the bore over part length of the longitudinal extent of the bar while retaining at least one end part length of the bar in tubular form.

4. A method as claimed in any one of the preceding claims in which the volume of the bore of the bar over the length thereof in which the rack teeth are to be formed substantially corresponds to the volume of a longitudinally extending recess which would be formed in a solid bar and within the extent of which recess the material of the solid bar would be displaced to form an array of rack teeth corresponding to that array which would be formed from the tubular bar.

5. A method as claimed in any one of the preceding claims which comprises locating in the bore of the metal bar a tubular metal plug, collapsing the wall of the tubular bar together with the wall of the plug substantially to close the bore of the plug and displacing the material of said plug and bar to form the array of rack teeth.

6. A method as claimed in any one of the preceding claims which comprises providing the tubular bar with its grain extending longitudinally thereof and coin pressing the bar to form therein the array of rack teeth so that the grain substantially follows the form of each tooth to be continuous over the array of rack teeth and each tooth is devoid of end grain, the teeth thus formed not being subjected to subsequent machining.

7. A method as claimed in any one of the preceding claims in which the tubular bar is substantially cylindrical.

8. A method as claimed in any one of the preceding claims which comprises heating the bar, at least over the part length thereof within which the rack teeth are to be formed, to facilitate flow of the metal during displacement thereof.

9. A method as claimed in any one of the preceding claims which comprises work hardening the surface of the rack teeth by coin pressing the teeth in the bar.

10. A method as claimed in any one of the preceding claims which comprises determining mathematically the form of the rack teeth which are to be provided for the rack member; producing a computer programme in accordance with said mathematical determination; utilising said programme to computer control a tool to machine on a coin pressing die component a profile which is complementary to said rack teeth and applying the so machined die to coin press the rack teeth in the metal bar.

11. A method of manufacturing a longitudinally extending rack member for a rack and pinion assembly substantially as herein described with reference to the accompanying illustrative drawings.

12. A rack member when manufactured by the method as claimed in any one of the preceding claims.

Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1981.
Published at the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.